

DESCRIPTION

APPARATUS FOR HOLDING OPTICAL ELEMENT, BARREL, EXPOSURE
APPARATUS, AND DEVICE PRODUCING METHOD

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TECHNICAL FIELD

The present invention relates to an optical element holding device, and more particularly, to a holding device 10 that enables highly accurate adjustment of the position of an optical element. The present invention provides a holding device, a barrel including the holding device, an exposure apparatus including the barrel, and a device manufacturing method including exposure performed with the exposure 15 apparatus.

BACKGROUND ART

In the prior art, a plurality of optical elements that 20 form a projection optical system of a projection exposure apparatus are held by holding devices, which enable accurate adjustment of the positions of the optical elements in the optical axis direction and the attitudes of the optical elements, such as tilt. The adjustment of the positions and 25 the attitudes of the optical elements corrects aberrations and controls aberration fluctuations, which would be caused by changes in atmospheric pressure and absorption irradiated heat.

30 A holding device for adjusting the position of an optical element through automatic control has been disclosed (refer to patent publication 1). The holding device includes an inner ring for holding the peripheral edge of a movable lens, and an outer ring arranged outside the inner ring 35 connected to the inner ring. The outer ring includes an

actuator. Displacement of the actuator is transmitted to the inner ring by a displacement enlargement mechanism so as to displace the movable lens. A sensor is attached to the outer ring to monitor the position of the movable lens. A barrel 5 including the holding device is relatively compact.

To enable the manufacturing of high-density and fine-pitch semiconductor devices, projection exposure apparatuses are required to perform exposure with higher resolutions.

10 There is a tendency for projection exposure apparatuses to use exposure light with shorter wavelengths. For example, the projection exposure apparatuses may use ArF excimer lasers ($\lambda = 193$ nm) or F₂ lasers ($\lambda = 157$ nm). The use of exposure light with shorter wavelengths contributes to enhancing resolution.

15 When exposure light having a wavelength of 200 nm or shorter is used, the existence of absorption substances, such as water, oxygen, and organic substances, in the optical path of the exposure light, would greatly attenuate the intensity 20 of the exposure light. In view of this, the holding device described in the patent publication 1 supplies purge gas into the barrel to remove water, oxygen, and organic substances, which that may be present in the optical path of the exposure light, from the barrel. However, a gap is formed between the 25 outer ring and the actuator. The purge gas may leak from the gap or ambient air (gas including oxygen, water, and organic substances) may flow through the gap into the inner space of the barrel. Therefore, a jacket is arranged around the barrel, and the space surrounded by the jacket is filled with purge 30 gas.

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2001/0038500

35 The space surrounded by the jacket accommodates a signal

communication coated cable, which is connected to the sensor, and a power feeding coated cable, which is connected to the actuator. The coated cables may generate a subtle amount of chemical pollutants (outgas), such as organic substances. The
5 space surrounded by the jacket is connected to the inner space of the barrel through the gap described above. The subtle amount of chemical pollutants generated by the coated cables may flow from the space surrounded by the jacket into the inner space of the barrel through the gap described above, and
10 may absorb the exposure light or fog the lenses accommodated in the barrel.

DISCLOSURE OF THE INVENTION

15 The present invention provides an optical element holding device that enables adjustment of the position and attitude of an optical element without disturbing the purge atmosphere formed interior of a barrel.

20 To achieve the above object, one aspect of the present invention provides an optical element holding device including a frame member. A holding member, arranged in the frame member, holds the optical element. A displacement portion is displaced in a direction intersecting with an optical axis of
25 the optical element by a driving force applied from outside the frame member. A transmission portion transmits displacement of the displacement portion to the holding member. The transmission portion displaces the holding member in a direction substantially parallel to the optical axis of
30 the optical element. Since drive sources that may generate chemical pollutants are arranged outside the frame member, the influence of chemical pollutants on the optical element is reduced.

35 In one embodiment, the displacement portion is displaced

within a plane that is orthogonal to the optical axis of the optical element. This reduces the dimension (thickness) of the optical element holding device along the optical axis of the optical element. Further, since the driving force is applied 5 within the plane orthogonal to the optical axis of the optical element, the driving force does not cause the frame member to be distorted along the optical axis of the optical element.

One embodiment further includes a driving member, 10 attached to the frame member, for generating the driving force, wherein the driving member urges the displacement portion in a direction intersecting with the optical axis of the optical element. In this case, since the driving member is mounted on the frame member, the internal structure of the 15 frame member is simple.

In one embodiment, the driving member includes a driving element and a housing, connected to the displacement portion, for accommodating the driving element. The housing includes a 20 coupling portion for transmitting a driving force generated by the driving element to the displacement portion. In this case, the driving force applied from the outside of the frame member is transmitted to the displacement portion via the housing.

25 In one embodiment, the driving member includes a rough adjustment mechanism for roughly adjusting the position of the holding member, and a fine movement mechanism for finely adjusting the position of the holding member. This structure enables rough adjustment and fine adjustment of the position 30 of the displacement portion to be performed accurately and quickly.

In one embodiment, the fine movement mechanism includes 35 a piezoelectric element. The piezoelectric element is easily controlled, has a quick response, and generates a strong and

stable driving force. Thus, the piezoelectric element is suitable for use in adjusting the attitude of the optical element.

5 One embodiment further includes a guiding portion for guiding the displacement portion in a manner that the displacement portion is displaced in a limited direction. This structure enables the holding member for holding the optical element to move accurately.

10 One embodiment further includes an urging member, arranged between the displacement portion and the frame member, for urging the displacement portion toward the frame member. This structure enables the attitude of the optical element to be controlled in a manner accurately following the displacement of the displacement portion.

15 In one embodiment, the transmission portion is a rod having one end, connected to the holding member in a manner rotatable and tilttable in any direction, and another end, connected to the displacement portion in a manner rotatable and tilttable in any direction. The one end and the other end of the rod are connected by an axis tilted relative to a direction in which the displacement portion is displaced. This structure enables part of the holding member to be moved parallel to the optical axis of the optical element by displacing the displacement portion within the plane orthogonal to the optical axis of the optical element.

20 In one embodiment, the displacement portion is one of three displacement portions that are arranged on the frame member, and the transmission portion is one of three transmission portions associated with the displacement portions, with each transmission portion including two rods connected to the associated displacement portion. This

structure enables the optical element to be kinematically supported.

One embodiment further includes a vibration attenuating mechanism, arranged between the frame member and the displacement portion, for attenuating vibration of the displacement portion generated by the driving force. In this case, the attitude of the optical element is adjusted appropriately without the transmission portion and the holding member receiving stress.

In one embodiment, the vibration attenuating mechanism includes a friction member fixed to one of the frame member and the displacement portion and slidably contacting the other one of the frame member and the displacement portion. In this case, the simple structure effectively attenuates vibrations.

In one embodiment, at least two of the frame member, the displacement portion, the guide portion, and the transmission portion are monolithically formed as a single structure body. For example, the single structure body is formed through engraving machining and includes a connecting portion connecting the at least two of the frame member, the displacement portion, the guide portion, and the transmission portion to one another. The plurality of components are formed integrally. As a result, the number of components decreases, the structure becomes simple, the relative positions of parts are accurately determined, unnecessary stress is not generated, and the rigidity of the structure becomes high.

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One embodiment further includes a displacement detection mechanism having a detector arranged inside the frame member for detecting displacement of the holding member, and a monitoring portion arranged outside the frame member for monitoring a detection result of the detector from outside the

frame member. The monitoring portion enables the detection result to be read while maintaining the hermetic state of the frame member. In this case, the displacement of the holding member may be understood without disturbing the purge
5 atmosphere inside a barrel.

One embodiment further includes a seal for isolating an inner space of the frame member from the outer side of the frame member and hermetically sealing the inner space of the
10 frame member. In this case, the holding device maintains a high-level purge atmosphere formed inside a barrel without particularly using a cover for covering the barrel.

The holding device may be incorporated in a barrel. The
15 barrel solely achieves a high-level purge atmosphere. The barrel may include, for example, a projection optical system for projecting an image of a predetermined pattern formed on a mask onto a substrate. The barrel may be incorporated in an exposure apparatus. The exposure apparatus accurately corrects
20 aberrations and is thus suitable for use in a lithography process included in the manufacturing processes of precision devices. The exposure apparatus enables high-quality devices to be manufactured.

25 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of an exposure apparatus including an optical element holding device according to a preferred embodiment of the present invention;

30 Fig. 2 is a perspective view showing the optical element holding device;

Fig. 3 is a plan view showing the optical element holding device;

35 Fig. 4 is a cross-sectional view taken along line A-A in Fig. 3;

Fig. 5 is a partially enlarged plan view of Fig. 3;
Fig. 6 is a partially enlarged view of Fig. 4;
Fig. 7 is a schematic diagram of the optical element holding device according to the preferred embodiment;
5 Fig. 8 is a schematic diagram of the optical element holding device according to the preferred embodiment;
Fig. 9 is a partial cross-sectional view of Fig. 4;
Fig. 10 is a front view showing a scale;
Fig. 11 is a flowchart schematically showing a device
10 manufacturing method; and
Fig. 12 is a flowchart showing part of a method for manufacturing a semiconductor device.

BEST MODE FOR CARRYING OUT THE INVENTION

15 An optical element holding device according to a preferred embodiment of the present invention will now be described. First, an exposure apparatus 31 will be briefly described with reference to Fig. 1. The exposure apparatus 31 includes a light source 32, an illumination optical system 33, a reticle stage 34 holding a reticle Rt serving as a mask, a projection optical system 35, and a wafer stage 36 holding a wafer W serving as a substrate.

25 The light source 32 oscillates, for example, F₂ laser light having a wavelength of 157 nm. Alternatively, the light source 32 may oscillate KrF excimer laser light having a wavelength of 248 nm or ArF excimer laser light having a wavelength of 193 nm. The present invention is advantageous when applied to the exposure apparatus 31 using light having relatively short wavelengths, such as F₂ laser light, ArF excimer laser light, and extreme ultraviolet (EUV) light having a wavelength of 13 nm.

35 The illumination optical system 33 includes various lens

systems including optical integrators, such as a fly-eye lens and a rod lens, a relay lens and a condenser lens, and an aperture stop, which are not shown in the drawings. Laser light emitted from the light source 32 passes through the 5 illumination optical system 33 so that the light is adjusted to be exposure light EL, which uniformly illuminates a pattern on the reticle Rt.

The reticle stage 34 has a placement surface on which 10 the reticle Rt is placed. The reticle stage 34 is arranged in a manner that its placement surface is substantially perpendicular to the optical axis of the projection optical system 35 at the light emitting side of the illumination optical system 33, that is, the object surface side of the 15 projection optical system 35 (incident side of the exposure light EL).

The projection optical system 35 includes optical elements 37, such as lenses. The projection optical system 35 20 is accommodated in a barrel 39, which is assembled by stacking a plurality of barrel modules 39a. Each barrel module 39a holds one or two optical elements 37.

Some (five in Fig. 1) of the plurality of barrel modules 25 39a include holding devices 38 for holding the optical elements 37. The other barrel modules 39a may also include the holding devices 38 or holding devices that differ in structure from the holding devices 38.

30 The wafer stage 36 has a placement surface on which the wafer W is placed. The placement surface of the wafer stage 36 is arranged to intersect with the optical axis direction of the projection optical system 35 at the image forming side of the projection optical system 35 (the side at which the 35 exposure light EL is emitted). An image of the pattern on the

reticle R_t illuminated with the exposure light EL is reduced by a predetermined reduction magnification by the projection optical system 35. Then, the image is projected and transferred onto the wafer W placed on the wafer stage 36.

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The holding device 38 will now be described. Fig. 2 is a perspective view showing a barrel module 39a including the holding device 38. Fig. 3 is a plan view showing the barrel module 39a including the holding device 38. Fig. 4 is a cross-sectional view taken along line A-A of Fig. 3.

10 As shown in Fig. 2, the holding device 38 includes an annular frame member 41 and three supporting members 42 for holding the optical element 37. As shown in Fig. 3, the frame member 41 includes an inner ring 43, which functions as a holding member, an outer ring 44, displacement portions 70, parallel link portions 71, and transmission link portions 72.

15 The outer ring 44 includes a side wall portion 44a, which has an outer circumferential surface, and an annular flat plate portion 44b, which is arranged at the inner side of the side wall portion 44a. An annular fastening portion 40 is further arranged at the top and bottom ends of the side wall portion 44a.

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25 The fastening portion 40 includes flat upper and lower fastening surfaces 40a. The upper fastening surface 40a has an annular groove 40b for accommodating an O-ring (refer to Fig. 4). Each fastening surface 40a has a plurality of bolt holes 40c formed at equiangular intervals. The O-ring is set in the annular groove 40b, and the upper fastening surface 40a is contacted with the lower fastening surface 40a of another barrel module 39a. Bolts are then inserted in the bolt holes 40c and fastened by nuts. In this way, the upper and lower 30 fastening surfaces 40a are fastened together. The O-ring set 35

in each of the plurality of barrel modules 39a ensures high gas sealing efficiency of the barrel modules 39a assembled together in the manner described above. Depending on a pressure difference between the inside and the outside of the 5 barrel module 39a, the barrel module 39a may have a plurality of annular grooves 40b for accommodating a plurality of O-rings, or may use a different sealing member, such as a gasket, instead of an O-ring.

10 As shown in Fig. 3, three piezoelectric element drive portions 46 are arranged on the side wall portion 44a of the outer ring 44 at intervals of 120 degrees. Further, three sensor heads 47, which function as monitoring portions, are arranged on the side wall portion 44a at positions
15 respectively deviated from the three piezoelectric element drive portions 46 by a distance corresponding to 60 degrees. An area of the side wall portion 44a excluding the areas in which the piezoelectric element drive portions 46 and the sensor heads 47 are arranged is formed as a closed surface.
20 This structure improves the gas sealing efficiency of the outer ring 44.

The frame member 41 will now be described. The frame member 41 is formed by machining a metal material, such as 25 stainless steel, using slit machining techniques or engraving machining techniques with a cutter, a drill, an end mill, laser processing, or electric discharge processing. The metal material is first cut into a disk shape material, and the cut disk shape material is machined to have a thickness that does 30 not cause interference with the optical element 37. A circular hole is then formed in the central vicinity of the disk shape material. The disk shape material is then partially cut to conform to the shape of the inner ring 43. Afterwards, the displacement portions 70, the parallel link portions 71, and 35 the transmission link portions 72 are formed using cutting and

separating techniques, such as planer slit processing or three-dimensional engraving machining. The portions 70, 71, and 72 are not completely separated, but are connected to one another by connecting portions (LPU, LPL, and EH1 to EH4). The 5 connecting portions are flexible, and enable the portions 70, 71, and 72 to be tilttable in a predetermined direction. The inner ring 43, the outer ring 44, the displacement portions 70, the parallel link portions 71, and the transmission link portions 72 are formed integrally from the same material. The 10 relative positions of these portions are determined with high precision, and each of these portions is free form unnecessary stress. In this case, the expanding and contracting stroke of each piezoelectric element 65 is increased with a superior linearity and converted into the displacement of the inner 15 ring 43.

The inner ring 43, the outer ring 44, the displacement portions 70, the parallel link portions 71, and the transmission link portions 72 will now be described with 20 reference to Fig. 5.

The displacement portion 70 is arranged in the vicinity of the piezoelectric element drive portion 46 as shown in Fig. 5.

25 The parallel link portion 71 functions to guide the displacement portion 70. More specifically, the set of parallel link portions 71 arranged on opposite sides of the displacement portion 70 guides the displacement portion 70. 30 The direction in which the displacement portion 70 is displaced is restricted with precision by the set of parallel link portions 71. The parallel link portions 71 will now be described in detail. The parallel link portions 71 include a right inner link 71RF and a right outer link 71RB, which are 35 arranged at the right of the displacement portion 70, and a

left inner link 71LF and a left outer link 71LB, which are arranged at the left of the displacement portion 70 as viewed in Fig. 5.

5 The right inner link 71RF is connected to the displacement portion 70 by an elastic hinge EH1 and connected to the flat plate portion 44b of the outer ring 44 by an elastic hinge EH2. The elastic hinges EH1 and EH2 have axes substantially parallel to the optical axis AX. The right inner
10 link 71RF rotates about the elastic hinge EH1 and tilts with respect to the displacement portion 70. The right inner link 71RF rotates about the elastic hinge EH2 and tilts with respect to the flat plate portion 44b. The elastic hinge EH1 and the elastic hinge EH2 are positioned in a manner that a
15 plane including the axis of the elastic hinge EH1 and the axis of the elastic hinge EH2 is perpendicular to the direction in which the piezoelectric element drive portion 46 is driven.

20 The right outer link 71RB is connected to the displacement portion 70 by an elastic hinge EH3 and connected to the flat plate portion 44b by an elastic hinge EH4. The elastic hinges EH3 and EH4 have their axes substantially parallel to the optical axis AX. The right outer link 71RB rotates about the elastic hinge EH3 and tilts with respect to
25 the displacement portion 70. The right outer link 71RB rotates about the elastic hinge EH4 and tilts with respect to the flat plate portion 44b. The elastic hinge EH3 and the elastic hinge EH4 are positioned in a manner that a plane including the axis of the elastic hinge EH3 and the axis of the elastic hinge EH4
30 is perpendicular to the direction in which the piezoelectric element drive portion 46 is driven.

35 Accordingly, the plane including the axes of the elastic hinge EH1 and the elastic hinge EH2 is parallel to the plane including the axes of the elastic hinge EH3 and the elastic

hinge EH4. The plane including the axes of the elastic hinge EH1 and the elastic hinge EH3 is parallel to the plane including the axes of the elastic hinge EH2 and the elastic hinge EH4. A rectangular formed by connecting the axes of the 5 elastic hinges EH1 to EH4 is a parallelogram.

The left inner link 71LF and the left outer link 71LB are symmetric to the right inner link 71RF and the right outer link 71RB with respect to a line of action AL, which coincides 10 with the drive direction of the piezoelectric element drive portion 46. The functions of the left inner link 71LF and the left outer link 71LB are equivalent to the functions of the right inner link 71RF and the right outer link 71RB.

15 As a result, the parallel link portions 71 restrict the movement of the displacement portion 70 with respect to the flat plate portion 44b of the outer ring 44 in the direction perpendicular to the optical axis AX. In detail, with the left inner link 71LF and left outer link 71LB and the right inner 20 link 71RF and right outer link 71RB being symmetric to each other with respect to the line of action AL, the interaction between the pair of parallel link portions 71 offsets a force that is applied orthogonally to the line of action AL. As a result, the displacement portion 70 is guided linearly with 25 precision along the line of action AL, which is perpendicular to the optical axis AX.

The transmission link portions 72 function as transmission portions. Each set of transmission link portions 30 72 is formed by a set of push rods. The set of push rods is formed by a first rod 72R arranged at the right of the line of action AL and a second rod 72L arranged at the left of the line of action AL. Each of the rods 72R and 72L includes an outer end portion closer to the side wall portion 44a and an 35 inner end portion farther from the side wall portion 44a. As

shown in Fig. 3, the rods 72R and 72L become closer to each other as the side wall portion 44a becomes near. The outer end portion of the first rod 72R is connected to the displacement portion 70 by an outer rod pivot LPL. The inner end portion of 5 the first rod 72R is connected to the inner ring 43 by an inner rod pivot LPU. The outer rod pivot LPL and the inner rod pivot LPU are formed integrally with the displacement portion 70 and the inner ring 43 by combining slit machining with engraving machining, which engravess the upper and lower end 10 surfaces of the structure. The upper and lower surfaces of the inner ring 43 are engraved so that the outer rod pivot LPL and the inner rod pivot LPU have the designed depths. This enables the three-dimensional first rod 72R to be formed.

15 The first rod 72R is tilttable and pivotal in any direction about each of the outer rod pivot LPL and the inner rod pivot LPU.

20 The outer rod pivot LPL and the inner rod pivot LPU have different depths from the front surface and the rear surface of the flat plate portion 44b. The inner rod pivot LPU is arranged to be higher than the outer rod pivot LPL. As a result, a line PL connecting the inner rod pivot LPU and the outer rod pivot LPL (the axis of the first rod 72R) has a 25 predetermined angle of deviation (angle of elevation) in the displacement direction of the displacement portion 70. The second rod 72L is formed symmetric to the first rod 72R with respect to the line of action AL.

30 The operation of the transmission link portion 72 will now be described. The outer end portion of the transmission link portion 72, which is connected to the displacement portion 70 by the outer rod pivot LPL, is displaced linearly in the direction perpendicular to the optical axis AX. When 35 the transmission link portion 72 is pressed by the

displacement portion 70 in the direction perpendicular to the optical axis AX, the movement of the inner end portion (rod pivot LPU) of the transmission link portion 72 is restricted in the direction of the optical axis AX. The movement of the 5 plurality of transmission link portions 72 causes the inner ring 43 to be kinematically driven. This will be described later.

Hereafter, the line PL connecting the outer rod pivot 10 LPL and the inner rod pivot LPU may be referred to as the axis PL of the transmission link portions 72. An angle formed by the axis PL and a plane orthogonal to the optical axis AX is, for example, about 10 to 15 degrees. Thus, when the outer end portion of the transmission link portion 72 is pressed 15 horizontally, the outer end portion of the transmission link portion 72 is displaced horizontally but the inner end portion of the transmission link portion 72 is displaced upward along the optical axis AX.

20 Further, a displacement amount (distance) by which the inner end portion of the transmission link portion 72 is displaced is larger than a displacement amount (distance) by which the outer end portion is displaced. In the present embodiment, piezoelectric elements like the piezoelectric 25 elements 65 are used as drive sources. Each piezoelectric element 65 responds quickly to an applied voltage, and expands and contracts by a stable stroke (displacement amount). Each piezoelectric element 65 also exhibits an extremely large driving force. Such piezoelectric elements 65 are suitable for 30 controlling the positions and the attitudes of the optical elements 37. However, the expanding and contracting stroke of the piezoelectric element 65 is typically small. The expanding and contracting stroke of the piezoelectric element 65 needs to be increased. The deviation angle described above has the 35 function of converting the expanding and contracting direction

of the piezoelectric element 65, and the function of increasing the expanding and contracting stroke of the piezoelectric element 65 to a sufficiently high level to control the position of the optical element 37.

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As shown in Fig. 3, the optical element 37 is a lens, such as a circular convex lens or a circular concave lens. The optical element 37 is made of a glass material having a breaking strength of a predetermined value or higher, such as 10 synthetic quartz or fluorite. As shown in Fig. 4, a flange portion 37a is formed on a peripheral edge of the optical element 37.

The diameter of the optical element 37 is substantially 15 the same as the inner diameter of the inner ring 43. As shown in Fig. 3, the three supporting members 42 are arranged at equiangular intervals along the inner circumference of the inner ring 43. The optical element 37 is supported by the 20 three supporting members 42. As shown in Fig. 9, each supporting member 42 includes a base member 79 and a clamp member 78. The base member 79 and the clamp member 78 clamp the flange portion 37a of the optical element 37. The base member 79 includes a flexure structure for absorbing factors 25 that would disturb the state of the optical surface of the optical element 37 (e.g., fine waves or distortions of the surface of the main body of the exposure apparatus 31 and the surface of the fastening portion 40 of the frame member 41). Such disturbance factors are given from an external device to 30 the supporting members 42. Even when the flatness of the inner ring 43 changes due to external distortions transmitted through the frame member 41, such changes are absorbed by the supporting members 42 arranged between the optical element 37 and the inner ring 43. This structure prevents the optical element 37 from being subjected to stress or the optical 35 surface of the optical element 37 from being subjected to

disturbing factors.

The piezoelectric element drive portion 46, which functions as a fine movement mechanism, will now be described 5 with reference to Fig. 6. The piezoelectric element drive portions 46 are mounted on the side wall portion 44a of the outer ring 44 (refer to Fig. 2). The side wall portion 44a has introduction holes 48, which are formed to extend toward the center (optical axis AX) of the outer ring 44.

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A cylindrical piezoelectric element housing 54 is inserted through the introduction hole 48. The piezoelectric element housing 54 includes a bottom surface portion 55 and an annular flange 56 formed on an outer surface of a middle 15 portion of the housing 54 in the longitudinal direction. A semispherical projection 57 is formed in the center of the bottom surface portion 55 of the piezoelectric element housing 54.

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The flange 56 of the piezoelectric element housing 54 comes in contact with a drive portion 74, which is formed inside the displacement portion 70. The flange 56 is fixed by a fixing ring 75. The drive portion 74 accurately determines the relative positions of the piezoelectric element housing 54 25 and the displacement portion 70. The fixing ring 75, which is fixed to the displacement portion 70 by screws, prevents the relative positions of the drive portion 74 and the flange 56 from changing.

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A sleeve-shaped seal house 49 is fitted in the introduction hole 48. More specifically, the seal house 49 is fixed to the side wall portion 44a. Annular grooves 50 and 51 are formed in the inner and outer surfaces of the seal house 49, respectively. An O-ring 52 is fitted in the annular groove 35 50. An O-ring 53 is fitted in the annular groove 51. The seal

house 49, which has substantially the same inner diameter as the outer diameter of the piezoelectric element housing 54, is arranged between the inner wall surface of the introduction hole 48 and the outer circumferential surface of the seal house 49. The O-ring 52 ensures sealing between the piezoelectric element housing 54 and the seal house 49. The O-ring 53 ensures sealing between the seal house 49 and the introduction hole 48. The O-rings 52 and 53 also permit sliding between the piezoelectric element housing 54, the seal house 49, and the side wall portion 44a.

An annular pressing block 58 is fixed to the side wall portion 44a in the vicinity of the introduction hole 48 by screws. A piezoelectric element cap 59, which covers the opening of the pressing block 58, is fixed to the pressing block 58 by a screw (refer to Fig. 5). The piezoelectric element cap 59 has a screw hole that extends along the center line of the piezoelectric element housing 54. A rod portion 61 of a rough movement screw 60 is screwed into the screw hole and a lock nut 64. A semispherical projection 62, which faces toward the center of the outer ring 44, is formed on the distal end of the rod portion 61 of the rough movement screw 60. A head portion 63 of the rough movement screw 60 is disk-shaped. The lock nut 64 is fastened with the piezoelectric element cap 59 to fix the rough movement screw 60.

The piezoelectric element housing 54 accommodates the cylindrical piezoelectric element 65. The piezoelectric element 65 slightly expands and contracts in response to an applied voltage and displaces the displacement portion 70 with the drive portion 74. The piezoelectric element 65 includes a conical recess 66, which is formed in a central portion of the inner end surface closer to the optical axis AX, and a conical recess 67, which is formed in a central portion of the outer end surface farther from the optical axis AX. When the

piezoelectric element 65 is accommodated in the piezoelectric element housing 54, the conical recess 66 is engaged with the semispherical projection 57. The rough movement screw 60 is screwed so that the conical recess 67 is engaged with the 5 semispherical projection 62. A gap is formed between the piezoelectric element housing 54 and the piezoelectric element 65, so that the piezoelectric element 65 comes in contact with the piezoelectric element housing 54 only at its conical recess 66. A cap-shaped electrode 68 covers the outer end portion of the piezoelectric element 65. The piezoelectric element housing 54 and the electrode 68 are electrically insulated from each other. A driving voltage for driving the piezoelectric element 65 is supplied to the piezoelectric element drive portion 46 from a controller (not shown) via a 10 cable (not shown).
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The operation of each portion of the holding device performed when the piezoelectric element 65 is driven will now be described.

20 The position of the outer end surface of the piezoelectric element 65 is determined by the engagement between the conical recess 67 and the semispherical projection 62 of the rough movement screw 60. When the piezoelectric element 65 expands and contracts in this state, the 25 piezoelectric element 65 urges the semispherical projection 57 of the piezoelectric element housing 54 toward the center of the outer ring 44. This causes the piezoelectric element housing 54 to move in the direction of the center (optical axis AX) of the outer ring 44. The flange 56 urges the displacement portion 70 in the direction of the optical axis AX. The displacement portion 70 is guided by the parallel link portion 71 (refer to Fig. 5) and is displaced in the direction perpendicular to the optical axis AX.
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As shown in Fig. 5, a pair of return springs 76, which extend parallel to the line of action AL, connects the displacement portion 70 and the flat plate portion 44b of the outer ring 44. The return springs 76 are urging members, such 5 as coil springs in an expanded state. The return springs 76 urge the displacement portion 70 toward the flat plate portion 44b of the outer ring 44, that is, in the direction that moves the displacement portion 70 away from the optical axis AX. When the supply of the driving voltage to the piezoelectric 10 element 65 is stopped and consequently contracts the piezoelectric element 65, the return springs 76 urge the displacement portion 70 so that the displacement portion 70 is moved away from the optical axis AX until the semispherical projection 57 of the piezoelectric element housing 54 comes in 15 contact with the conical recess 66.

The rough movement screw 60 is connected to the frame member 41 by the pressing block 58 and the piezoelectric element cap 59. When the head portion 63 of the rough movement 20 screw 60 is turned, the rod portion 61 moves forward or backward relative to the piezoelectric element cap 59. As a result, the distance between the semispherical projection 62 and the optical axis AX changes so that the initial position of the outer end surface of the piezoelectric element 65 25 changes. This changes the initial positions of the piezoelectric element housing 54 and the displacement portion 70. In this way, the rough movement screw 60 is used to roughly adjust the distance between the displacement portion 70 and the optical axis AX.

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As shown in Fig. 6, the flange 56 is an annular coupling portion arranged around the piezoelectric element housing 54. The drive portion 74 of the displacement portion 70 has an annular shape corresponding to the shape of the flange 56. The 35 flange 56 and the drive portion 74 transmit the driving force

of the piezoelectric element 65 uniformly to the displacement portion 70 along the line of action AL. The driving force is efficiently transmitted to the displacement portion 70 without generating forces that restrict the linear movement of the
5 displacement portion 70.

The piezoelectric element 65 accommodated in the piezoelectric element housing 54 is fixed in a manner that its conical recess 67 is fixed to the semispherical projection 62
10 of the rough movement screw 60. A driving force generated by the piezoelectric element 65 is transmitted to the piezoelectric element housing 54 via the conical recess 66 and the semispherical projection 57 and to the displacement portion 70 via the flange 56. The semispherical projection 57 is arranged at a position closer to the optical axis AX than
15 the flange 56, and the outer end surface of the piezoelectric element 65 is arranged outward from the side wall portion 44a of the outer ring 44. In the present embodiment, a piezoelectric element is not required to be arranged in the
20 narrow area between the outer ring 44 and the displacement portion 70, and the piezoelectric element 65 may be arranged in a relatively large space. This enables a large piezoelectric element to be used as the piezoelectric element 65. The expanding and contracting stroke of the piezoelectric element 65 is elongated as the piezoelectric element 65
25 becomes longer. Although a piezoelectric element is typically a driving element of which the expanding and contracting stroke is small, the structure of the present embodiment enables the piezoelectric element to greatly displace the
30 optical element 37 without increasing the size of the frame member 41. This further eliminates the need for increasing the size of the barrel and enables the driving elements, such as the piezoelectric elements 65, to be accommodated in the frame member 41.

In the structure of the present embodiment, sources that release chemical pollutants, such as actuators, electronic circuits, and cables, are not arranged in the inner space of the frame member 41 that communicates with the purge space.

5 The piezoelectric element housing 54 (and the sensor head 47) isolates the inner space of the frame member 41 from the outside of the frame member 41. The piezoelectric elements 65 that are not arranged in the inner space of the frame member 41 are easily replaceable without disturbing the purge

10 atmosphere. Further, by using the pressing block 58 and the piezoelectric element cap 59 in accordance with the size of the piezoelectric element 65, piezoelectric elements 65 of various sizes may be used. In this case, the size of the piezoelectric element 65 is changed without disturbing the

15 purge atmosphere.

As shown in Fig. 6, a friction mechanism 80, which functions as a vibration attenuating mechanism, is arranged to sandwich the upper and lower surfaces of each displacement portion 70. The friction mechanism 80 includes a friction house 81, which is fixed to the flat plate portion 44b of the outer ring 44. The friction house 81 has a recess facing the displacement portion 70. The recess accommodates a coil spring (friction spring) 82, which is compressed. A friction applying plate 83 is arranged on the distal end of the friction spring 82. The friction applying plate 83 is a flat spring member having one end fixed to the friction house 81 and the other end being free. The friction spring 82 strongly urges the free end of the friction applying plate 83 toward the displacement portion 70. As a result, when the driving force of the piezoelectric element drive portion 46 causes the displacement portion 70 to move, a friction force for reducing the movement is generated. Although the friction force is not large enough to stop the movement of the displacement portion 70, the

30 friction force is large enough to restrict drastic movement of

35

the displacement portion 70. The friction mechanism 80 sandwiching the upper and lower surfaces of the displacement portion 70 prevents the generation of vibrations that would affect exposure.

5

The friction mechanism 80 applies friction force to the displacement portion 70. More specifically, before the transmission link portion 72 elongates the expanding and contracting stroke of the piezoelectric element 65, the 10 friction mechanism 80 prevents vibration from being generated when the piezoelectric element drive portion 46 is driven. Thus, force or stress for reducing vibration is not directly applied to the transmission link portion 72 and the inner ring 43. Further, torque for displacing the displacement portion 70 15 is relatively large. Thus, the friction force of the friction mechanism 80 does not stop the displacement of the displacement portion 70. If a friction force for attenuating vibration is directly applied to the transmission link portion 72 or to the inner ring 43, the friction force may stop the 20 displacement of the transmission link portion 72 or the inner ring 43.

The attitude control of the optical element 37 will now be described with reference to Figs. 7 and 8. Figs. 7 and 8 25 schematically show the holding device 38.

The three displacement portions 70 are arranged at equiangular intervals of 120 degrees. These drawings do not show the piezoelectric element drive portions 46. The parallel 30 link portions 71 are arranged on opposite sides of each displacement portion 70. Each displacement portion 70 is connected to the inner ring 43 by a set of push rods, which form the transmission link portions 72. The interval between the two push rods increases as the inner ring 43 becomes 35 closer. Each push rod tilts upward with respect to the

horizontal plane. The displacement portions 70, the parallel link portions 71, and the transmission link portions 72 form three displacement link portions U1, U2, and U3.

5 Fig. 8 schematically shows only the inner ring 43, the displacement portions 70, and the transmission link portions 72.

10 The push rods in each set are symmetric to each other with respect to a plane including the optical axis AX. The displacement portions 70 are moved in the radial direction as shown in Fig. 8 to drive the inner ring 43. The quantitative relationship between the displacement amount of the displacement portion 70 and the attitude change of the inner 15 ring 43 will now be described.

20 The terms used hereafter will be defined. As shown in Fig. 8, an intersection point of the extension lines of the two push rods in each of the displacement link portions U1, U2, and U3 is referred to as a virtual pivot V. A plane defined by the three virtual pivots V is referred to as a pivotal plane. The pivotal plane is orthogonal to the optical axis AX when the displacement portions 70 are not displaced. A center of a circle extending through the three virtual pivots 25 V is referred to as an observation point C. It is apparent that the observation point C is on the pivotal plane. The observation point C is on the optical axis AX when the displacement portions 70 are not displaced.

30 A rectangular coordinate system will now be defined. The observation point C is used as an "origin" of the coordinate system when the displacement portions 70 are not displaced. As shown in Fig. 8, a line connecting the origin and the virtual pivot V of the first displacement link portion U1 is referred 35 to as an X axis, an axis distant from the X axis by an angle

of 90 degrees about the optical axis AX in the counterclockwise direction is referred to as a Y axis, and an axis orthogonal to the X axis and the Y axis is referred to as a Z axis. When the displacement link portions U1, U2, and U3
5 need to be distinguished from each other, symbols U1 to U3 will be added to the reference numerals, and will be referred to, for example, as transmission link portions 72U1 to 72U3, displacement portions 70U1 to 70U3, and virtual pivots VPU1 to VPU3.

10

The quantitative values related to the attitude change of the inner ring 43 occurring when the displacement portions 70 are displaced will be defined. When the attitude of the inner ring 43 is changed, the observation point C is
15 displaced. The amounts by which the observation point C is displaced along the X, Y, and Z axes are referred to as displacement amounts dx , dy , and dz , respectively. The attitude change of the inner ring 43 for fine adjustment of the optical system is extremely small. Thus, the attitude
20 change of the inner ring 43 may be divided linearly into the components of rotation amounts $d\theta_x$, $d\theta_y$, and $d\theta_z$ on the X axis, the Y axis, and the Z axis. The positive code of a value complies with the right hand screw rule with respect to the positive direction of the coordinate axes.

25

Among the six displacement amounts dx , dy , dz , $d\theta_x$, $d\theta_y$, and $d\theta_z$ for determining the attitude of the inner ring 43, the values of dx , dy , and $d\theta_z$ are apparently zero because of the structure. In other words, the inner ring 43 does not shift in
30 the X direction and the Y direction, that is, in the horizontal direction, the displacement portions 70 are displaceable only in the radial direction (the direction of the line of action AL), and do not rotate about the Z axis.

35

As described above, the attitude change ΔI of the inner

ring 43 is expressed as shown below.

$$\Delta I = (dx, d\theta_x, d\theta_y)^T$$

5 In the present embodiment, the displacement of the
displacement portion 70 that changes the attitude of the inner
ring 43 is a linear movement along the line of action AL.
Thus, the degree of freedom of the movement is expressed as 1.
The displacement amounts of the three displacement portions
10 70U1 to 70U3 are respectively defined as δ_1 , δ_2 , and δ_3 .

The displacement amounts of the displacement portions
70U1 to 70U3 may be expressed collectively as input
displacement $\Delta p = (\delta_1, \delta_2, \delta_3)^T$.

15 The attitude change ΔI corresponds linearly to the input
displacement Δp , that is, corresponds in one-to-one to the
input displacement Δp . This relationship is considered using a
transformation matrix A (three by three) as a linear
20 transformation of the expression shown below.

$$\Delta I = A \Delta p$$

Not only in the present embodiment but also in general
25 cases, the transformation matrix A is easily formulated based
on geometric considerations, and typically has an inverse
matrix.

More specifically, the following is satisfied.

30

$$\Delta P = A^{-1} \Delta I$$

This indicates that the adjustment amount (the input
displacement Δp) for achieving the attitude change ΔI of
35 desired optical elements from the viewpoint of the optical

adjustment is obtained using a simple calculation.

The transformation matrix A of the present embodiment is expressed below.

5

$$A = (a, Ra, R^2a)$$
$$a = (1/3 \tan\theta, 0, 2/3 r\tan\theta)^T.$$

Here, R is a rotation matrix at 120 degrees about the Z axis.

10

The transformation matrix A in the present embodiment is as described above. Appropriately setting θ or r optimizes the adjustment accuracy, the resolution, and the movable range. In this way, the driving of the displacement portions 70 changes 15 the attitude of the inner ring 43 via the transmission link portions 72.

The mechanisms described above are arranged inside the frame member 41.

20

As schematically shown in Fig. 7, the three displacement portions 70 of the outer ring 44 are connected to the three parallel link portions 71, respectively. Each displacement portion 70 is accurately guided by the relevant parallel link portions 71 and displaced linearly in the radial direction of 25 the outer ring 44. The displacement of the displacement portions 70 is transmitted to the inner ring 43 by the transmission link portions 72 so as to change the attitude of the inner ring 43. In this way, the inner ring 43 is 30 kinematically supported by the first to third displacement link portions U1 to U3. The basic idea of the present embodiment is to displace the displacement portions 70 so as to change the attitude of the inner ring 43.

35 A displacement detecting mechanism will now be described

with reference to Figs. 9 and 10. The frame member 41 includes three sensor heads 47 and three detectors 85. The sensor heads 47 are arranged on the outer ring 44. The detectors 85 are arranged on the inner ring 43. Each detector 85 includes a scale 86, which is displaced together with the inner ring 43.

The scale 86 is mounted on the inner ring 43 in the vicinity of the sensor head 47. As shown in Fig. 10, the scale 86 includes a flat plate facing the sensor head 47. A lattice functioning as graduations for forming an incremental linear encoder and an origin lattice indicating an origin are displayed on the flat plate. The optical sensor head 47 reads a graduation on the scale 86 and detects displacement of the inner ring 43, that is, displacement of the optical element 37.

The sensor head 47 is hermetically fitted to the opening of the outer ring 44 with an O-ring 87 arranged therebetween. The sensor head 47 includes an objective lens (not shown) for reading a graduation on the scale 86, and an optical sensor portion (not shown) for generating a detection signal that is in accordance with the read graduation. The objective lens is formed hermetically so that the objective lens does not affect the purge atmosphere inside the barrel 39. In the preferred embodiment, the optical sensor portion provides the detection signal to an external controller. The controller increments a count number in accordance with the received detection signal and calculates a displacement amount. The sensor head 47 is formed in a manner that its portions excluding the lens portion at the distal end are not exposed in the purge space. More specifically, the electronic circuit, the sensor main body, and the cables of the sensor head 47 are not exposed in the purge space. In other words, the sources for releasing chemical pollutants are not arranged in the purge space. Thus, the purge atmosphere is prevented from being disturbed.

The inner ring 43 has a reference surface 88 in the vicinity of the scale 86. A datum house 89 is arranged at the side of the frame member 41 facing the reference surface 88. The datum house 89 accommodates a stud 90 and a spherical 5 datum 91. The spherical datum 91 is mounted on the head portion of the stud 90. The spherical datum 91 has a spherical surface facing the inner ring 43. The spherical datum 91 and the stud 90 determine a reference position of the inner ring 43. More specifically, the inner ring 43 comes in contact with 10 the spherical datum 91 when the inner ring 43 is at the lowest reference position. If the inner ring 43 is not in contact with the spherical datum 91, the inner ring 43 is lowered. To lower the inner ring 43, the displacement portion 70 is displaced in the direction in which the displacement portion 15 70 moves away from the optical axis AX by loosening, as a general rule, the rough movement screw 60 of the neighboring piezoelectric element drive portion 46. Play may exist between the conical recesses 66 and 67 at both ends of the piezoelectric element 65 and the semispherical projection 57 20 of the piezoelectric element housing 54 or the spherical projection 62 of the rough movement screw 60 when the inner ring 43 is in contact with the spherical datum 91. In this case, the displacement portion 70 is displaced in the direction in which the displacement portion 70 moves toward 25 the optical axis AX by loosening, as a general rule, the rough movement screw 60 of the neighboring piezoelectric element drive portion 46 to a degree at which the inner ring 43 is not spaced from the spherical datum 91.

30 The exposure apparatus 31 shown in Fig. 1 includes the barrel 39, which is formed by the barrel modules 39a including the holding devices 38. As one example, the exposure apparatus 31 is manufactured in the manner described below.

35 First, at least one of the plurality of optical elements

37 including lenses and mirrors forming the illumination optical system 33 and the projection optical system 35 is held using the holding device 38. The illumination optical system 33 and the projection optical system 35 are incorporated in
5 the main body of the exposure apparatus 31, and their optical adjustment is performed. Cables for transmitting detection signals and drive signals are connected to the piezoelectric element drive portions 46 and the sensor heads 47. The piezoelectric element drive portions 46 and the sensor heads
10 47 are connected by these cables to a known computer-controlled controller. The controller calculates displacement of the optical elements 37 based on detection signals provided from the sensor heads 47. The controller generates drive signals in accordance with the calculated displacement and the
15 above expressions, and provides the piezoelectric element drive portions 46 with the drive signals. The piezoelectric element drive portions 46 are driven to change the attitudes of the optical elements 37.

20 Next, the wafer stage 36, which is formed by many mechanical parts, is mounted on the main body of the exposure apparatus 31 and wires are connected to the wafer stage 36. When the exposure apparatus is of a scanning type, the reticle stage 34 is also mounted. A gas supply pipe for supplying gas
25 into the optical path of exposure light is connected, and the inner space of the barrel is purged. For example, the inner space of the barrel is filled with N₂ after O₂ and moisture are completely removed from the inner space of the barrel. After the wires and the pipe are connected, overall adjustment of
30 the apparatus (including electricity adjustment and operation checking) is performed.

It is preferable that the components of the holding device 38 and the sealing members such as O-rings of the
35 holding device 38 be assembled after those components are

subjected to, for example, ultrasonic cleaning to remove impurities including working fluids and metallic substances, so that they do not release chemical pollutants. Further, it is preferable that the exposure apparatus 31 be manufactured 5 in a clean room in which the temperature, humidity, atmospheric pressure, and cleanliness are controlled.

In the preferred embodiment, fluorite and quartz are exemplified as the glass material for the optical element 37. 10 Examples of the glass material for the optical element 37 may further include crystals of lithium fluoride, magnesium fluoride, strontium fluoride, lithium-calcium-aluminum-fluoride, and lithium-strontium-aluminum-fluoride. Further, modified quartz, such as fluoride glass made of zirconium-barium-lanthanum-aluminum, quartz glass doped with fluorine, quartz glass doped with fluorine and hydrogen, quartz glass containing OH group, and quartz glass containing fluorine and OH group, may also be used.

20 A device manufacturing method including a lithography process performed by the exposure apparatus 31 will now be described.

Fig. 11 is a flowchart showing the manufacturing processes of devices such as semiconductor devices including 25 an IC and an LSI circuit, liquid crystal display devices, imaging devices (e.g., CCD), thin film magnetic heads, and micromachines. First, in step S201 (design step), the function and the performance of a device (microdevice) are designed 30 (e.g., the circuit of a semiconductor device is designed), and a pattern for realizing the function is designed. In step S202 (mask forming step), a mask (e.g., a reticle Rt) having the designed circuit pattern is formed. In step S203 (substrate manufacturing step), a substrate is manufactured using a 35 material such as silicon or a glass plate. The substrate may

be, for example, a silicon wafer W.

In step S204 (substrate processing step), the mask and the substrate are used and an actual circuit is formed on the
5 substrate by, for example, lithography. In step S205 (device assembling step), the substrate processed in step S204 is used and the device is assembled. Step S205 may include a dicing process, a bonding process, and a packaging process (including chip encapsulating).

10

In step S206 (inspection step), inspections including operation checking and durability testing of the device are performed. The device completed in this way is then shipped.

15

Fig. 12 is a detailed flowchart of step S204. When the device that is to be manufactured is a semiconductor device, the surface of the wafer W is oxidized in step S211 (oxidation step). In step S212 (CVD step), an insulation film is formed on the surface of the wafer W. In step S213 (electrode forming
20 step), an electrode is formed on the wafer W by vapor deposition. In step S214 (ion implantation step), ions are implanted into the wafer W. Each of steps S211 to S214 is a pretreatment process in each stage of the wafer processing. Each of steps S211 to S214 is selectively executed according
25 to a treatment process required in each stage of the wafer processing.

25

When the pretreatment processes described above are completed in the stages of the wafer processing, post treatment processes are performed in the manner described
30 below. In step S215 (resist forming step), a photosensitizing agent is first applied to the wafer W. In step S216 (exposure step), a circuit pattern of a mask (reticle Rt) is transferred onto the wafer W using the lithography system (exposure apparatus 31) described above. In step S217 (development
35

step), the wafer W exposed is developed. In step S218 (etching step), portions of the exposure member excluding portions on which the resist is remaining are removed by etching. In step S219 (resist removing step), the resist that has become
5 unnecessary after the etching is removed.

The pretreatment processes and the post treatment processes are performed repeatedly, so that a multiplex circuit pattern is formed on the wafer W.

10

The device manufacturing method according to the present embodiment uses the exposure apparatus 31 described above in its exposure process (step S216). The exposure light EL in a vacuum ultraviolet region enhances resolution. Further, the
15 method controls the exposure amount with high precision. As a result, the method enables devices with a minimum line width of 0.1 μm to be manufactured at a high yield.

The present embodiment has the advantages described
20 below.

(1) The piezoelectric element drive portions 46 and the sensor heads 47 are attached to the frame member 41. However, the outer ring 44 hermetically isolates the purge space from
25 the outside. Further, sources for releasing chemical pollutants, such as sensors, actuators, and cables, are not arranged in the inner space of the frame member 41 that communicates with the purge space. Thus, even when an F₂ laser is used as a light source, the optical elements 37 are
30 adjusted without disturbing the purge atmosphere.

(2) In the present embodiment, the driving force of the piezoelectric elements 65 mounted on the frame member 41 is transmitted to the inner ring 43 by the displacement portions
35 70 and the transmission link portions 72. This structure

enables such drive sources to be arranged outside the frame member 41 and simplifies the internal structure of the frame member 41.

5 (3) The displacement portions 70 are displaced toward the optical axis AX within the plane orthogonal to the optical axis AX. The piezoelectric element drive portions 46 are accommodated within the thickness of the frame member 41. As a result, the holding device 38 is compact. The driving force is
10 applied in parallel to the plane orthogonal to the optical axis AX. Thus, the frame member 41 is not distorted, the flatness of the holding device 38 is maintained, and the high sealing performance is maintained. Further, because this structure simplifies calculation required in the attitude
15 control of the optical element 37, the attitude control is executed with high accuracy and high reliability.

 (4) The inner ring 43 is kinematically supported by the three sets of push rods. Thus, the optical elements 37 are not
20 subjected to stress and are held precisely at the controlled attitude.

 (5) The piezoelectric elements 65 are accommodated in the piezoelectric element housing 54 arranged on the frame member 41. Thus, the piezoelectric elements 65 are replaceable from the outside of the frame member 41.
25

 (6) The piezoelectric elements 65 are displaced quickly, strongly, and accurately in response to a driving voltage.
30 Thus, the attitudes of the optical elements 37 are adjusted promptly and accurately.

 (7) The piezoelectric element housing 54 and the transmission link portions 72 increase the expansion and
35 contraction amount of the piezoelectric elements 65. Thus, the

positions and the attitudes of the optical elements 37 are adjusted using the piezoelectric elements 65 that typically have small expansion and contraction amounts.

5 (8) The driving of the piezoelectric elements 65 is controlled by the controller. Thus, the positions and the attitudes of the optical elements 37 in the optical axis direction are adjusted automatically. Further, the rough movement screw 60 is manually operated from outside the
10 holding device 38. Thus, the positions of the piezoelectric elements 65 are adjusted easily.

15 (9) The sensor head 47 for automatically detecting a graduation on the scale 86 may be combined with the controller so as to enable feedback control of the automatic adjustment of the optical element 37. The detector 85 uses the spherical datum 91 as a reference to accurately adjust the position of the optical element 37 with respect to the frame member 41. This structure improves the precision of the displacement
20 detection.

25 (10) The return springs 76 cause the displacement portions 70 to return to their initial positions when the displacement portions 70 are not receiving a driving force. In this case, no unnecessary stress is applied to the transmission link portions 72 or to the inner ring 43.

30 (11) The friction mechanism 80 having a simple structure attenuates vibrations during driving without applying unnecessary stress to the transmission link portions 72 or to the inner ring 43. The friction force of the friction mechanism 80 is adjustable by adjusting the intensity of the friction spring 82.

35 (12) The outer ring 44, the inner ring 43, the

displacement portions 70, the parallel link portions 71, and the transmission link portions 72 are formed integrally as a single metallic structure through, for example, engraving machining. The relative positions of these portions are
5 accurate, and these portions are not subjected to unnecessary stress. As a result, the linearity of the attitude control of the optical elements 37 is high.

(13) Each barrel module 39a is joined with another
10 barrel module 39b using the annular groove 40b formed in the fastening portion 40 so that the barrel 39 has high gas sealing efficiency.

(14) The exposure apparatus 31 including the barrel 39 having high gas sealing efficiency eliminates the need for a cover for maintaining the high-level purge atmosphere formed inside the barrel. As a result, when signals are provided as feedbacks from the sensor heads 47 using the optical elements 37 and the controller, the piezoelectric element drive
20 portions 46 adjust the positions and the attitudes of the optical elements 37 while maintaining the high-level purge atmosphere.

(15) The exposure apparatus 31 enables highly accurate semiconductor devices to be manufactured at a high yield using an F₂ laser while maintaining the high-level purge atmosphere.

The preferred embodiment may be modified in the following forms.

30 The drive elements are not limited to the piezoelectric elements and may be other drive elements, such as solenoids, hydraulic actuators, and linear motors.

35 Depending on the structures of the actuator and the

optical elements 37, the drive amount of the drive elements may be reduced instead of elongating the expanding and contracting stroke of the piezoelectric elements 65.

5 The displacement portions 70 are displaced within the plane perpendicular to the optical axis AX. Alternatively, the displacement portions 70 may be displaced in another direction intersecting with the optical axis AX.

10 The displacement portions 70 and the transmission link portions 72 do not have to be arranged at equiangular intervals.

15 Four or more transmission link portions may be arranged when the rigidity of the structure needs to be increased.

20 Although the transmission link portions 72 are arranged to intersect at the pivotal plane when the displacement portions 70 are not receiving a driving force, the present invention should not be limited to this structure.

25 Further, although the transmission link portions 72 are arranged symmetric with respect to the line of action AL, the transmission link portions 72 may be arranged in an asymmetric manner.

The transmission link portions 72 do not need to have the same length and same angle.

30 Although it is preferable to kinematically support the optical elements in a strict sense as in the preferred embodiment, the optical elements do not have to be supported completely kinematically as long as such supporting does not hinder the present invention.

In the preferred embodiment, the kinematically supporting structure is anomalous and restricts three of the six degrees of freedom. However, the kinematically supporting structure may have higher degrees of freedom as long as such a 5 structure applies a driving force in the direction intersecting with the optical axis AX of the optical elements 37.

Although the parallel link portions 71 are exemplified 10 as guide portions in the preferred embodiment, other guide portions may be used. For example, the guide portions may slide the displacement portions to restrict the movement of the displacement portions at their inside or outside.

15 Although the sensor head 47 reads the scale 86 inside the frame member 41 via the hermetically sealed lens in the preferred embodiment, the outer ring 44 may have a hermetically sealed monitoring window. The displacement detection method should not be limited to the optical reading 20 of the scale but may be one of various other detection methods including magnetic reading.

The present invention is not limited to the exposure apparatus using the projection optical system and may be 25 applied to a contact exposure apparatus for exposing a pattern of a mask placed in contact with a substrate, or a proximity exposure apparatus for exposing a pattern of a mask placed in proximity of a substrate. Further, the projection optical system of the exposure system may not be dioptric but may be 30 catadioptric.

The exposure apparatus of the present invention is not limited to the exposure apparatus that performs reduced projection exposure and may be, for example, an exposure 35 apparatus that performs non-magnified projection exposure or

an exposure apparatus that performs magnified projection exposure.

The present invention is applicable not only to
5 microdevices such as semiconductor devices but also to
exposure apparatuses for transferring a circuit pattern from a
mother reticle to a glass substrate or to a silicon wafer for
manufacturing a reticle or a mask used in light exposure
apparatuses, EUV exposure apparatuses, X-ray exposure
10 apparatuses, and electron beam exposure apparatuses. Exposure
apparatuses using DUV (deep ultraviolet) light and VUV (vacuum
ultraviolet) light typically use a transmissive reticle. Such
exposure apparatuses typically use quartz glass, quartz glass
doped with fluorine, fluorite, magnesium fluorine, or crystals
15 as a material for a reticle substrate. Further, X-ray exposure
apparatuses and electron beam exposure apparatuses of
proximity type use a transmissive mask (a stencil mask or a
membrane mask), and use, for example, a silicon wafer as a
mask substrate.

20
The present invention is applicable not only to the
exposure apparatus used for manufacturing semiconductor
devices but also to an exposure apparatus for transferring a
device pattern onto a glass plate in manufacturing displays
25 including an LCD. The present invention is further applicable
to an exposure apparatus used for transferring a device
pattern onto a wafer, such as a ceramic wafer, when
manufacturing thin film magnetic heads, or to an exposure
apparatus used for manufacturing imaging devices including a
30 CCD.

The present invention is applicable to a scanning
stepper for transferring a pattern of a mask onto a substrate
and moving a substrate in steps while the mask and the
35 substrate are moved relative to each other. The present

invention is further applicable to a step-and-repeat stepper for transferring a pattern of a mask onto a substrate and moving the substrate in steps in a state in which the mask and the substrate are still.

5

The light source for the exposure apparatus is not limited to an F₂ laser (157 nm) but may be an ArF excimer laser (193 nm), g-line (436 nm), i-line (365 nm), a KrF excimer

laser (248 nm), a Kr₂ laser (146 nm), or an Ar₂ laser (126 nm).

10 Harmonics obtained by amplifying single-wavelength laser light in an infrared region or a visible region that is oscillated from a DFB (distributed-feedback) semiconductor laser or a fiber laser using a fiber amplifier that is doped with, for example, erbium (or doped with erbium and ytterbium), and
15 converting the wavelength of the light into ultraviolet light using a nonlinear optical crystal may be used.